

Aviation Safety Program

Integrated Resilient Aircraft Control Project

Preliminary Technical Plan Summary

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This document was developed over the past several months by NASA to define the rationale, scope and detailed content of a comprehensive Aviation Safety, Integrated Resilient Aircraft Control research project. It contains reference to past work and an approach to accomplish planned work with applicable milestones, metrics and deliverables. The document also references potential opportunities for cooperation with external organizations in areas that are currently considered to be of common interest or benefit to NASA. This document should be considered a reference document and not a completed research plan.

1. Technical Plan

1.1 Relevance

1.1.1 Research Motivation and Technical Need

An evaluation of worldwide aircraft fatal accident data reveals the following accident categories to be large contributors: loss of control (which may include contributing factors from other categories), system and component failures, in-flight icing effects, and collisions with terrain, obstacles, and other aircraft. From 1987-2004 the combination of these categories resulted in 127 fatal accidents (56% of all fatal accidents) and 7830 fatalities (82% of all fatalities). In the U.S., aircraft loss of control and mid-air collisions remain the largest unresolved safety problems after assumed risk reduction from the Commercial Aviation Safety Team (CAST) plan implementation, with loss of control comprising approximately 68% and midair collisions comprising approximately 10% of the remaining risk.

Loss of control is an extremely complex problem that has a wide variety of causal and contributing factors which may occur separately or in combination. Historical and emerging causal and contributing factors can be categorized as adverse conditions (including system and component faults and failures, vehicle and propulsion system impairment and damage, vehicle configuration incompatibilities, software and hardware errors, crew input errors and inappropriate crew response), vehicle upset conditions (including operation beyond the normal flight envelope, unstable modes of motion, stall and/or departure from controlled flight, uncommanded motions due to asymmetric thrust, failures, damage, and out-of-control motions), and external hazards (including icing conditions, wake vortices, turbulence, and wind shear). These adverse, upset, and hazard conditions will be collectively referred to as “abnormal” conditions in this plan.

Although crew training is conducted for adverse and upset conditions, the training is limited due to the need for improvements in the simulation models that are currently available. Studies by the National Institute for Aerospace (NIA) (*Aviation Plan for American Leadership*) and the National Transportation Safety Board (NTSB), for example, have cited the need to better model ice accumulation and its dangerous effect on a vehicle’s flying qualities in current training simulators. Studies by the Commercial Aviation Safety Team (CAST) have also cited the need for better physical modeling of vehicle dynamics in abnormal conditions for improved pilot training. Higher fidelity modeling is also crucial when improved pilot training is not sufficient for aircraft recovery, specifically in the development of automated control system technologies to recover from vehicle damage.

Aircraft survivability under vehicle damage is another area of National importance. In particular, eight transport accidents occurred from 1977-2005, resulting in 1,114 fatalities. The NIA report cited damage adaptive control and recovery as providing potentially life-saving technology. The USAF Large Aircraft Survivability Initiative (LASI), the Department of Homeland Security (DHS), and the U.S. Naval Air Systems Command (NAVAIR) all have a high interest and need for technologies that enable damage modeling, safety-of-flight and recoverability assessment, and damage mitigation for transport aircraft. While these interests center around safety risks resulting from security threats, the development of methods and tools for generic damage scenarios is of vital importance.

Mid air collisions have also been cited as a safety concern. Safe operation within the current and Next Generation Air Transportation System (NGATS) is a problem of National importance. The NGATS will involve a system-wide transformation resulting in the following characteristics: network-enabled information access; performance-based services; layered, adaptive security; weather assimilated decision making; broad-area precision navigation; trajectory-based aircraft operations; “equivalent visual” operations; and “super density” operations. Technologies that enable vehicle-based autonomy will therefore be required to enable safe operation under both normal and abnormal conditions. The NIA report, *Aviation Plan for American Leadership*, identified reliable autonomous control technologies as a key technology element for maturation

(priority 4 out of 29, and cited as a critical technology enabler for achieving safe, mixed manned and unmanned terminal and enroute operations).

1.1.2 Research Mission, Goals, Objectives, and Problem Definition

The long-term mission of Integrated Resilient Aircraft Control (IRAC) Project is to reduce (or eliminate) aircraft loss-of-control accidents and ensure safe flight under flight/safety-critical adverse, upset, and hazard conditions in the current and next-generation air transportation system. The long-term goals are to develop technologies to prevent or recover from aircraft loss-of-control by detecting, characterizing, and mitigating historical and emerging precursors to these events, and to provide onboard control resilience functions for continuously assessing and managing vehicle performance and control capability to ensure flight safety and recoverability under multiple and cascading adverse, upset and hazard conditions. Long term IRAC objectives are to develop integrated multidisciplinary methods, tools, and techniques for the: characterization, detection, and prediction of coupled adverse/upset/hazard conditions and their effects on aircraft safety of flight; loss-of-control prevention, mitigation, recovery, and adaptive flight planning under multiple and cascading adverse/upset/hazard conditions; and assessment of complex integrated adaptive systems (analytical, simulation, and experimental validation, verification, and predictive capability assessment; software safety assurance).

1.1.3 Technical Challenges, Current State of the Art, and Planned Research

Aircraft prevention and recovery from loss-of-control requires the ability to identify and assess, via physics-based modeling and simulation, loss-of-control precursors and causal/contributing factors (e.g., icing, upsets, and failures/damage) and their impact on aircraft safety of flight and recoverability. These factors lead to coupled vehicle dynamics effects, and must therefore be characterized using an integrated multidisciplinary modeling approach that includes aerodynamics, vehicle dynamics, structures, and propulsion. Current modeling and simulation methods and techniques enable some coupling between aerodynamics and propulsion, and between aerodynamics and aeroelastic structural effects. However, current methods and techniques do not include the capability for high-fidelity modeling and simulation of coupled massively separated flows affecting aerodynamics, vehicle dynamics, structures (including aeroplasticity and discrete source damage), and propulsion effects. Towards solving this technical challenge, we will focus on technologies for the integrated multi-disciplinary modeling of aerodynamics, vehicle dynamics, structures, and propulsion in order to characterize abnormal conditions and their impact on aircraft dynamic response.

Prevention and recovery from aircraft loss of control also requires advanced multi-disciplinary multi-objective control methods to detect, identify, and mitigate a variety of dissimilar causal and contributing factors onboard and in real time. Since loss of control under these conditions can occur very quickly and the time available for recovery is limited, the vehicle state must be constantly assessed and all available control power utilized to maintain (or regain) stability and safe flight within the current (and future) air transportation system. Current adaptive and reconfigurable control methods are not multi-disciplinary since they often address only the vehicle dynamics. The lack of multi-objective stability, control, and trajectory management functions in the current adaptive control methods render them ineffective in dealing with abnormal conditions whereby dissimilar and coupled effects exist. Our research will focus on the development of coupled adaptive flight, engine, and airframe control technologies that are integrated with trajectory, thrust, and loads management technologies. Control autonomy requirements for effective trajectory management under abnormal conditions will also be considered in the presence of vehicle dynamics constraints including propulsion and airframe effects.

The transition of simulation models and resilient control methods for improved crew training and onboard control under abnormal conditions will require new validation and software verification methods that include predictive capability assessment techniques. In particular, rigorous methods for adaptive software verification and validation must be developed to ensure that control system software failures will not occur, to ensure the control system functions as required, to eliminate unintended functionality, and to demonstrate that

certification requirements can be defined and satisfied. Current methods focus on models and systems designed for normal operation under nominal conditions. Validation methods to be developed in the first 5 years include analysis methods for adaptive control systems, simulation based methods for guided Monte Carlo evaluations, and experimental test methods for ground/flight testing under abnormal conditions. Methods and tools for probabilistic uncertainty characterizations and risk analysis will also be developed for experimental risk mitigation and as a prerequisite for establishing predictive capability assessment methods. Research into software verification and safety assurance methods for safety-critical adaptive systems will also be initiated.

The planned research is highly innovative in the multidisciplinary approach to be employed and in the level of integration to be achieved. Integrated modeling, control, and V&V methods will be developed across disciplines (aerodynamics, propulsion, airframe structures), across abnormal conditions (failures/damage, icing, upsets), as well as across control components (mitigation of failures/damage and icing effects, upset prevention and recovery, and trajectory management under abnormal conditions). Integration across application domains (vehicle configurations, missions, uncertainties and abnormal conditions), as well as across other research thrusts within the AvSP (Integrated Vehicle Health Management (IVHM), Integrated Intelligent Flight Deck (IIFD), and Aircraft Aging and Durability (AAD)) and other programs (Airspace Systems Program (ASP), Fundamental Aeronautics Program (FAP), and Space Exploration) will be achieved in the long-term, with efforts to facilitate this initiated during the first five years.

1.1.4 Leveraged Research

Control upset prevention and recovery (CUPR) and damage adaptive control systems (DACS) research was initiated under the NASA Aviation Safety and Security Program (AvSSP). The CUPR effort focused on aerodynamics modeling of vehicle upset conditions, on systems technologies for failure detection, identification, and accommodation through control reconfiguration, and on some preliminary methods for upset recovery. The DACS research initiated the development of a multidisciplinary damage modeling approach to characterizing the coupled multidisciplinary effects of vehicle damage. Prior work in damage adaptive control focused on simplistic assumptions regarding aerodynamics effects of damage (e.g., % loss of lift due to wing damage), without any consideration given to coupled multidisciplinary effects. Research into intelligent flight control systems (IFCS) was initiated under NASA's Vehicle Systems Program (VSP). This research focused on the development of direct adaptive control methods for failure accommodation using neural networks. The development of an integrated V&V process (including analytical, simulation-based, and experimental methods) for safety-critical control systems was initiated under the AvSSP CUPR activity, as well as the SMART-T activity under the NASA Flight & Systems Demonstration (F&SD) Program. Icing research was also conducted under the AvSSP, and includes the development of aero models for the NASA Twin Otter and Cessna CJ2 (business jet) based on sub-scale wind tunnel tests and verified through flight tests.

These past research efforts will be leveraged in the planned work and expanded to include: modeling of unsteady aerodynamic effects and separated flow conditions for vehicle upsets, airframe structure and propulsion system performance effects under vehicle upset conditions, icing effects characterization and detection (under turbulence conditions representative of icing phenomena), multidisciplinary damage modeling and control mitigation, upset prevention and recovery, and trajectory management (including thrust and loads management) under damage, impairment (e.g., due to icing), and/or upset conditions. V&V research efforts will be extended to include additional methods focused on adaptive control systems and on software safety assurance for IRAC technologies. Research into predictive capability assessment for validation domains that are not coincident with the application domain will also be initiated.

1.2 Technical Approach

(Details forthcoming.)

1.3 Milestones, Metrics, and Schedule

(Details forthcoming.)